BIOMORPHIC EXPLORERS & BIOMORPHIC MISSIONS

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Presentation Draft 4th IAA International Conference on Low Cost Planetary Missions to be held May 2 - 5, 2000 at The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland USA

Biomorphic explorers are a new paradigm in mobile explorers that capture key features and mobility attributes of biological systems, to enable new scientific endeavors. The general premise of biomorphic explorers is to distill the principles offered by natural mechanisms to obtain the selected features/functional traits and capture the biomechatronic designs and minimalist operation principles from nature's success strategies. Bio-morphic explorers are a unique combination of versatile mobility controlled by adaptive, fault tolerant biomorphic algorithms to autonomously match with the changing ambient/terrain conditions. Significant scientific payoff at a low cost is realizable by using the potential of a large number of such cooperatively operating biomorphic explorer units.

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BIOMORPHIC EXPLORERS

- A MULTIDISCIPLINERY SYSTEM CONCEPT FOR SMALL, DEDICATED, LOW-COST EXPLORERS THAT CAPTURE SOME OF THE KEY FEATURES OF BIOLOGICAL ORGANISMS
  - Small... 100-1000g (useful space/terrestrial exploration functions are implementable* using this mass)
- CONDUCTED WORKSHOP, AUG 19-20, 1998
  - SPONSORED BY NASA/JPL
  - DICK URBAN, DARPA WAS ON OUR ADVISORY BOARD
  - WEBSITE: http:/nmp.jpl.nasa.gov/bees/
  - AN ENTHUSIASTIC RESPONSE: OVER 150 PARTICIPANTS

* JPL DOCUMENT D-14879A, JPL DOCUMENT D-16300A, JPL DOCUMENT D-16500, AUTHOR: SARITA THAKOOR

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THE CHALLENGE TO OBTAIN A BIOMORPHIC ROBOT

- NATURE'S CREATIONS
  - PRIMARILY ORGANICS BASED
  - EVOLUTION LED SURVIVING DESIGN AND MINIMALIST OPERATIONAL PRINCIPLES ARE INHERENT
  - GEOLOGICAL TIME SCALE HAS BEEN USED FOR EVOLUTION
- BIOMORPHIC ROBOT
  - PRIMARILY INORGANICS BASED, THE INGREDIENTS/MATERIALS AVAILABLE TO US
  - NEEDS TO BE CREATED BY DISTILLING THE PRINCIPLES OFFERED BY NATURAL MECHANISMS. CAPTURING THE BIOMECHATRONIC DESIGNS AND MINIMALIST OPERATION PRINCIPLES FROM NATURE'S SUCCESS STRATEGIES
  - DO IT WITHIN A LIFETIME

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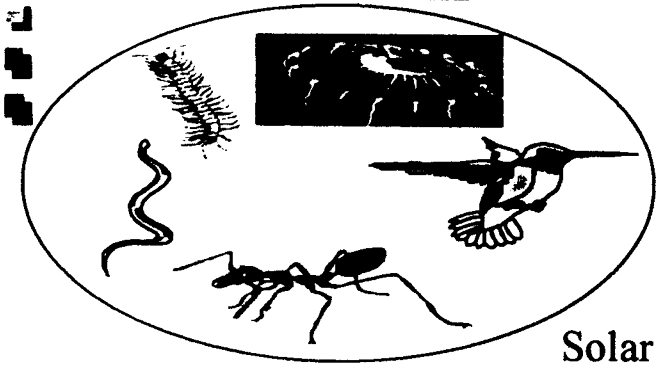
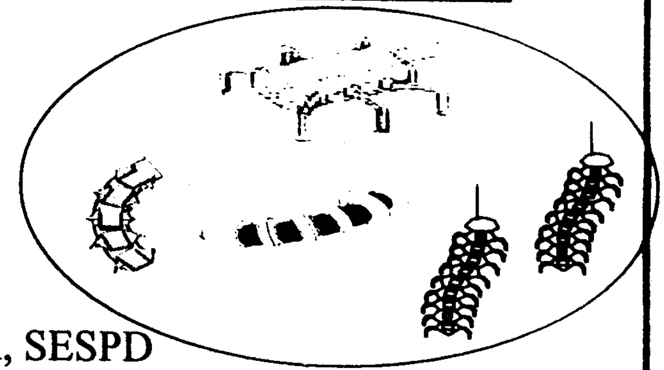
1st NASA/JPL WORKSHOP ON BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS

INSPIRATION

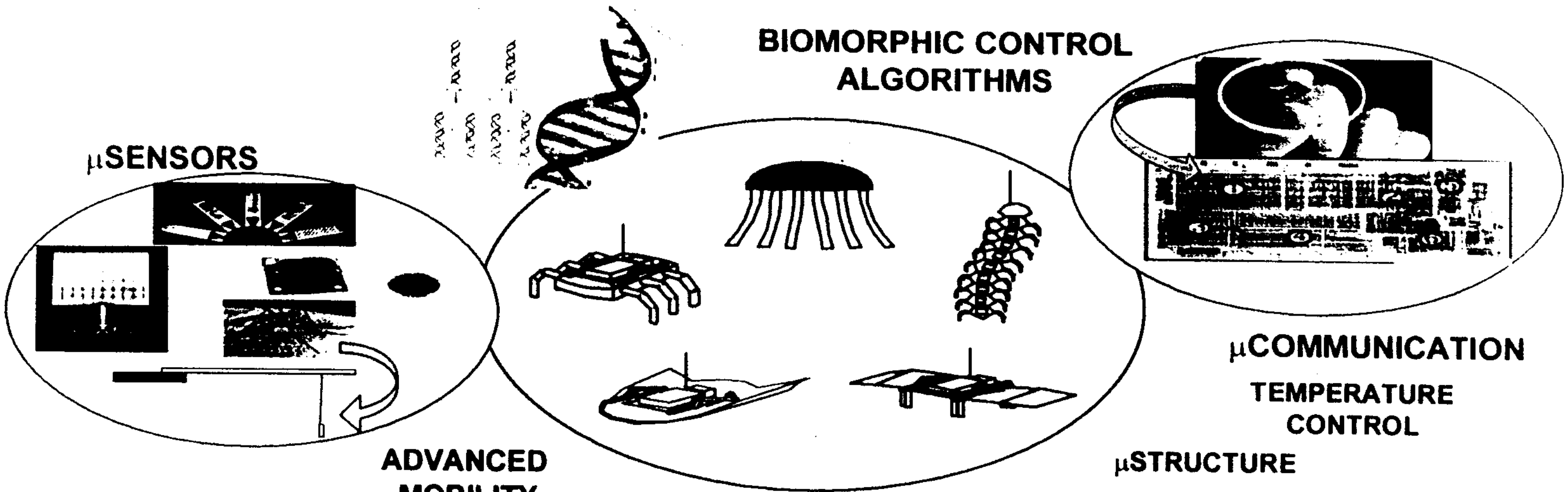


IMPLEMENTATION



August 19 - 20, 1998
Jet Propulsion Laboratory
Pasadena, CA
Auditorium 180 - 101

Sponsored by NASA/JPL
Solar System Exploration Program, SESPD
New Millennium Program, NMP
Space Mission Technology Development Program, TAP
Center for Integrated Space Microsystems, CISM



TECHNICAL POC: SARITA THAKOOR
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Significant scientific payoff at a low cost is realizable by using the potential of a large number of such cooperatively operating biomorphic explorer units. A classification of these with example candidates in each category follows. The biomorphic flight systems are particularly attractive for solar system exploration because of their potential large range, unique imaging perspective, and the access to here-to fore inaccessible sites that they would provide.

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BIOMORPHIC EXPLORERS (BEES) SUBSYSTEMS BREAKDOWN

- **BEES**
  - **1.0** VERSATILE MOBILITY: ACTUATORS, BIOMECHATRONIC DESIGNS
    - 1.1 MOBILE FLIGHT SYSTEMS
      - 1.1.1 POWERED, MICROFLYERS, HELICOPTERS
      - 1.1.2 GLIDERS
      - 1.1.3 ORNITHOPTERS
    - 1.2 MOBILE SURFACE/SUBSURFACE SYSTEMS
      - 1.2.1 CRAWLERS
      - 1.2.2 BURROWERS
      - 1.2.3 OTHERS
  - **2.0** ADAPTIVE CONTROLS
  - **3.0** BIOINSPIRED SENSOR SUITE
    - 3.1 N² RECOGNITION CUBE
    - 3.2 SENSOR FUSION
  - **4.0** BIOMORPHIC COMMUNICATIONS
    - 4.1 EM
    - 4.2 CHEMICAL
    - 4.3 ACOUSTIC
  - **5.0** BIOMORPHIC COOPERATIVE BEHAVIORS DISTRIBUTED OPERATIONS
    - 5.1 CASCADED DAISY CHAIN
    - 5.2 MARSUPIAL
    - 5.3 COLLABORATIVE, MULTI-HUB
    - 5.4 HEIRARCHICAL, SUBSUMPTIVE
    - 5.5 CLUSTER, LOCAL HUBS
  - **6.0** BIOMORPHIC ENERGY GENERATION/CONVERSION
    - 6.1 PHOTOSYNTHESIS
    - 6.2 ATP-ADP

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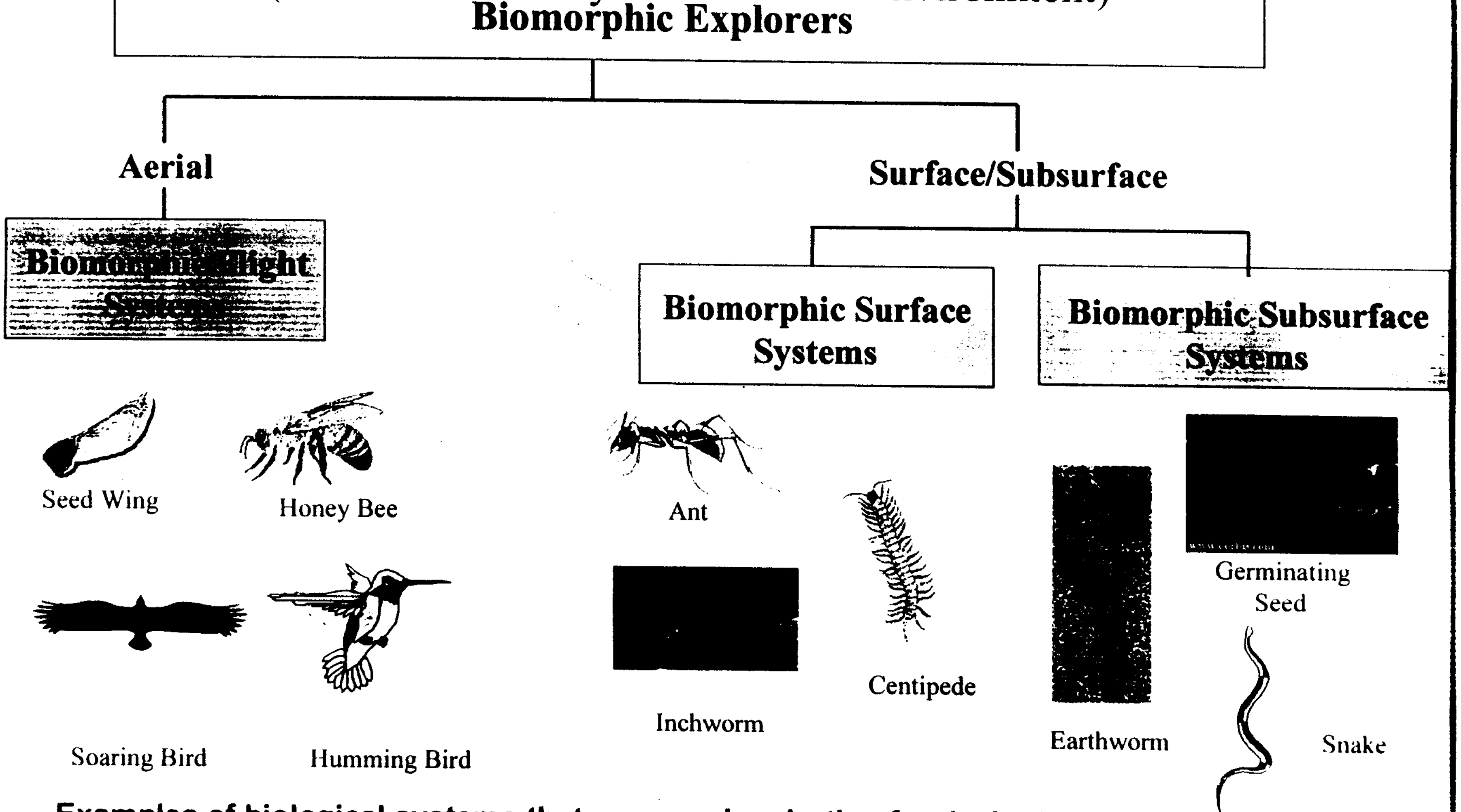
Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)



Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class

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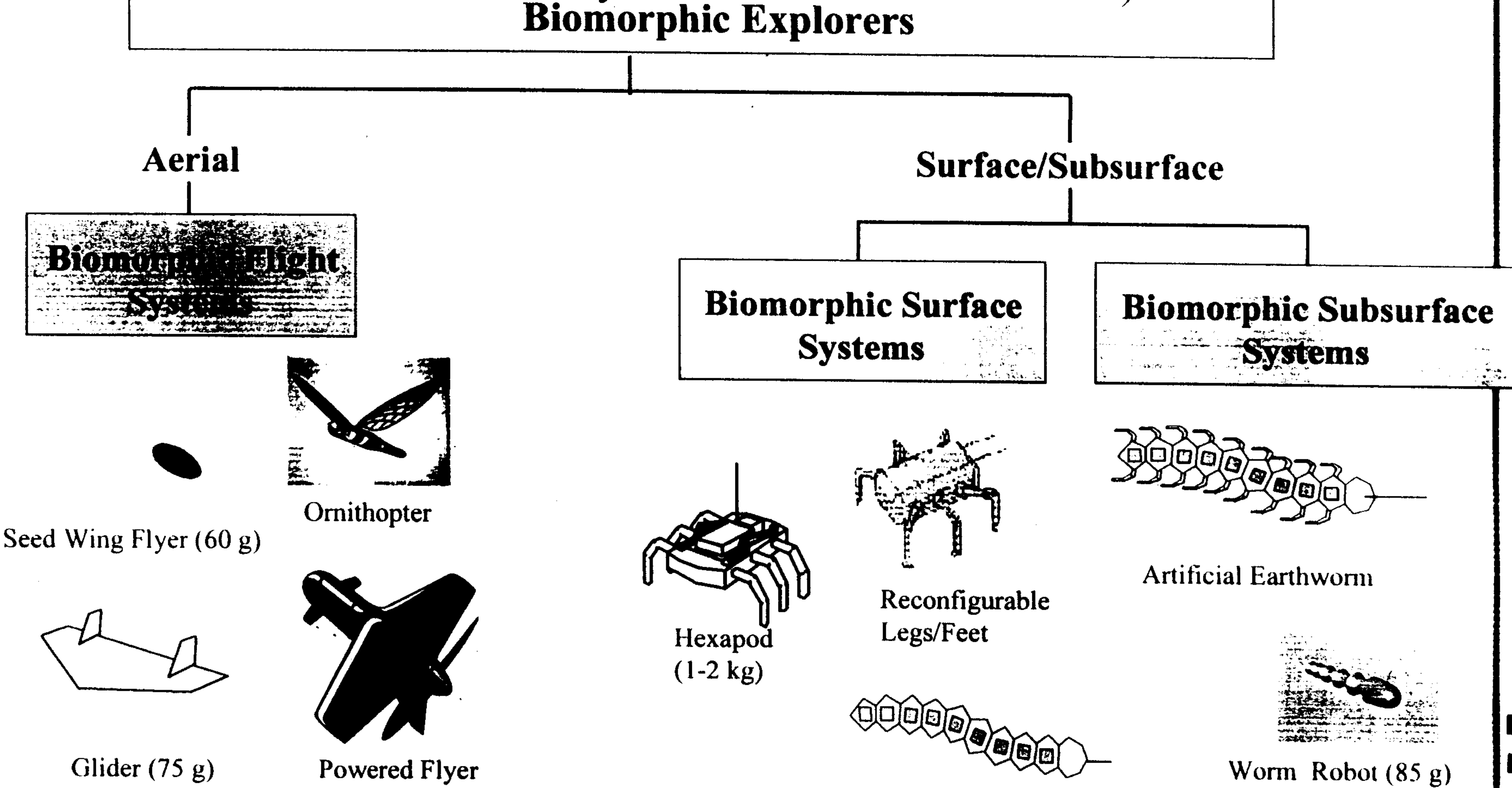
Biomorphic Explorers: Classification
(Based on Mobility and Ambient Environment)



Candidate biomorphic explorers on the drawing board, with mass of design under study in parentheses

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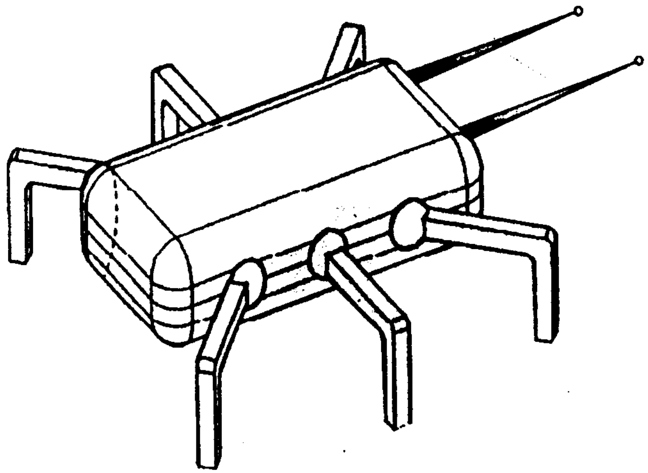
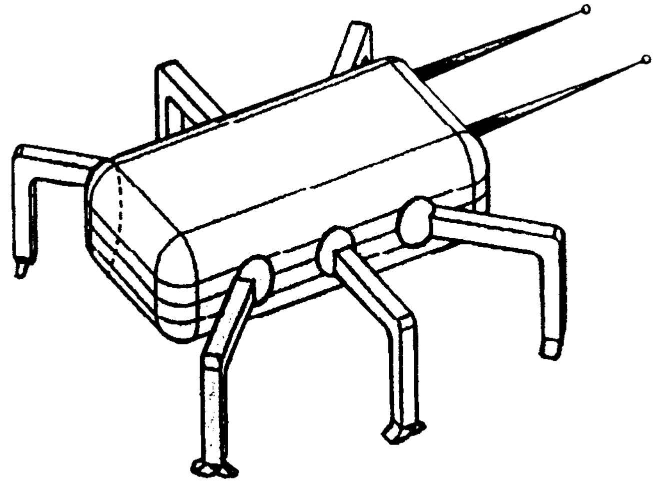
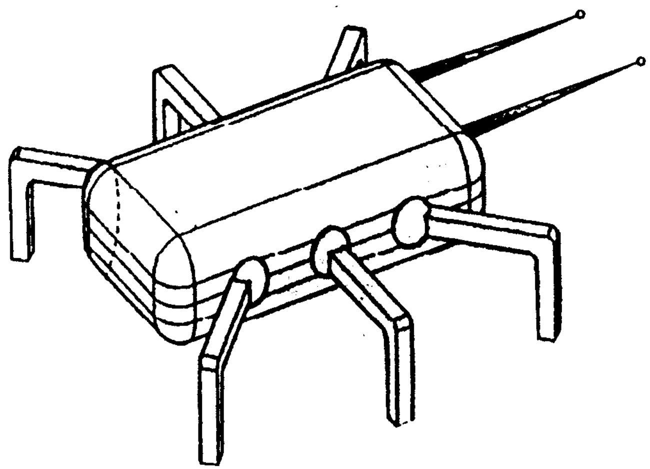
MULTITERRAIN RECONFIGURABLE LEGGED EXPLORER



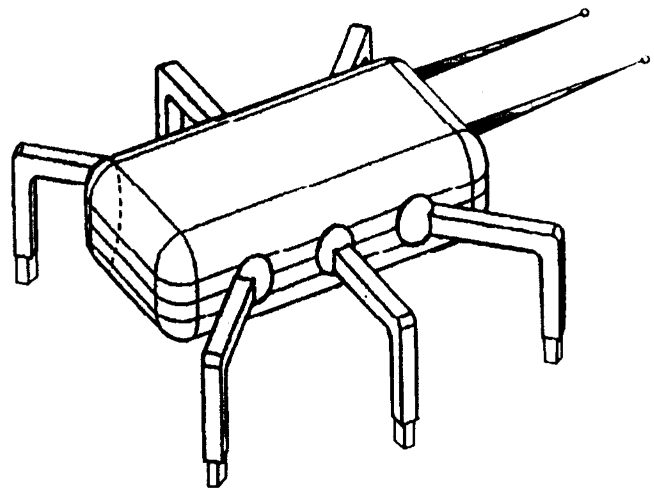
NARROW FOOTPRINT



WIDE FOOTPRINT



SHORT LEG



LONG LEG

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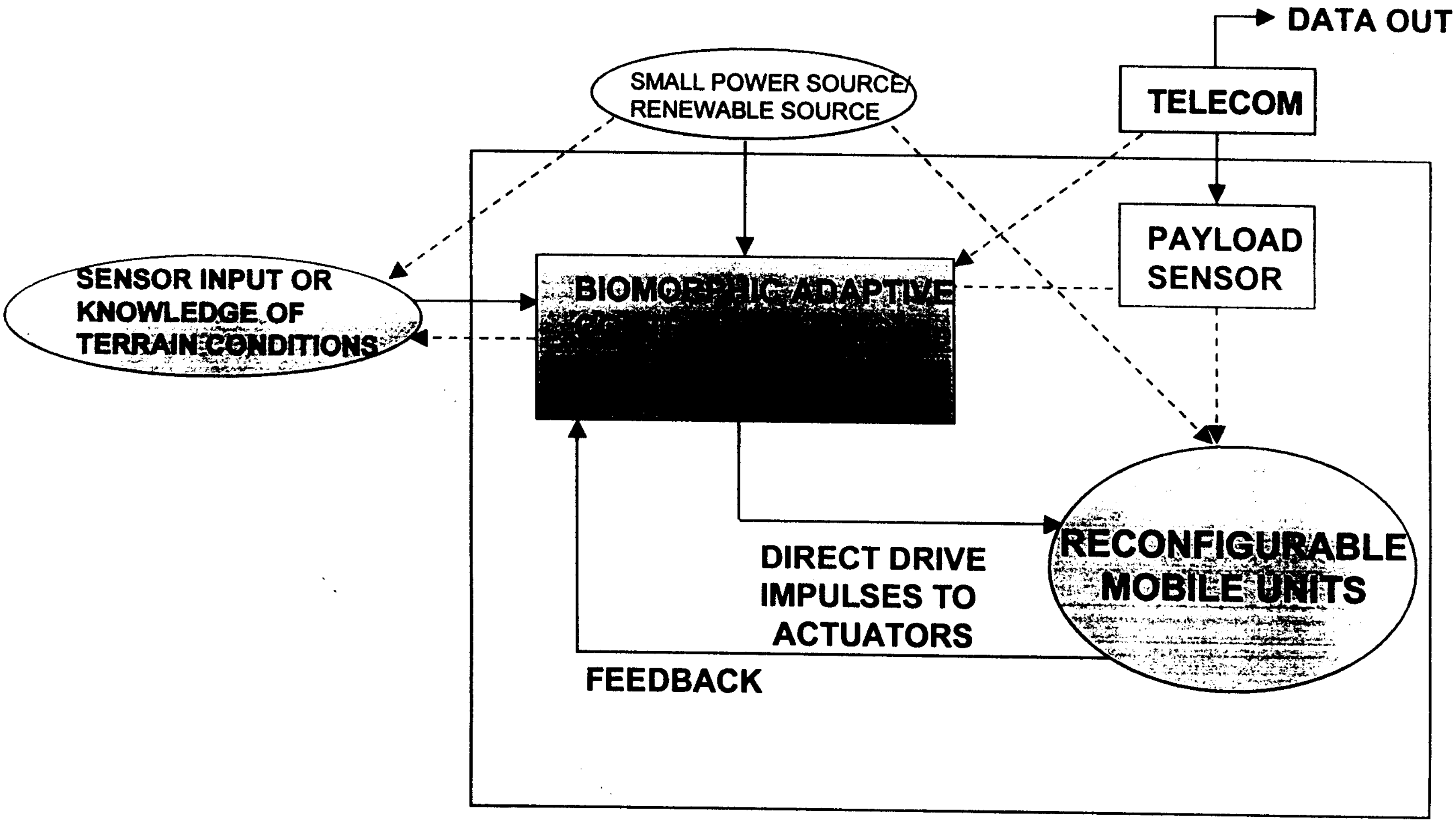
Distributed Control Operational Schematic



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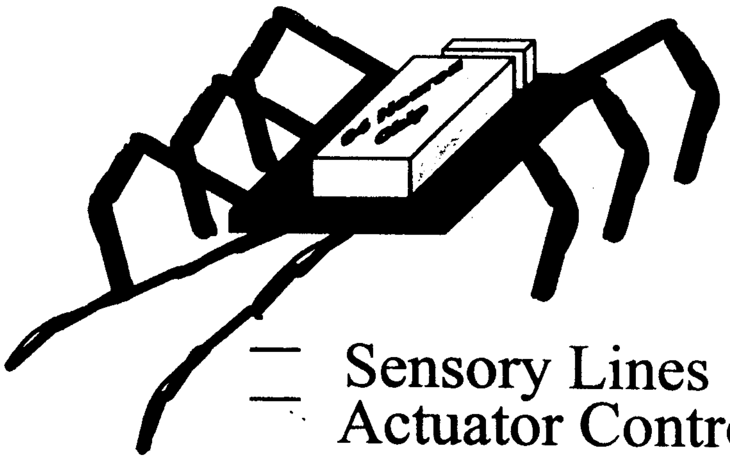
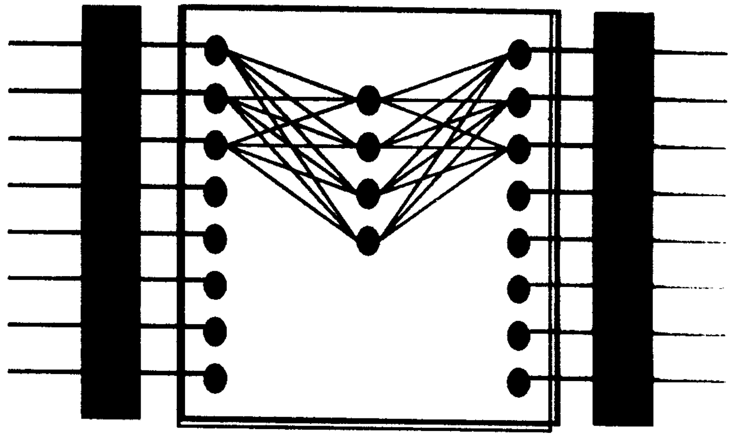
Neurally Controlled Biomorphic Explorer



— Sensory Lines
— Actuator Controls

Neural connections mapped on 64 Neural Network (NN) Chip



JPL's 64 NN chip characteristics:
- Low Weight (5 g)
- Small Size (1 cm x 1 cm)
- Low Power (12 mW)
- High Speed (~250 ns)
- Programmable Neural Network Architecture

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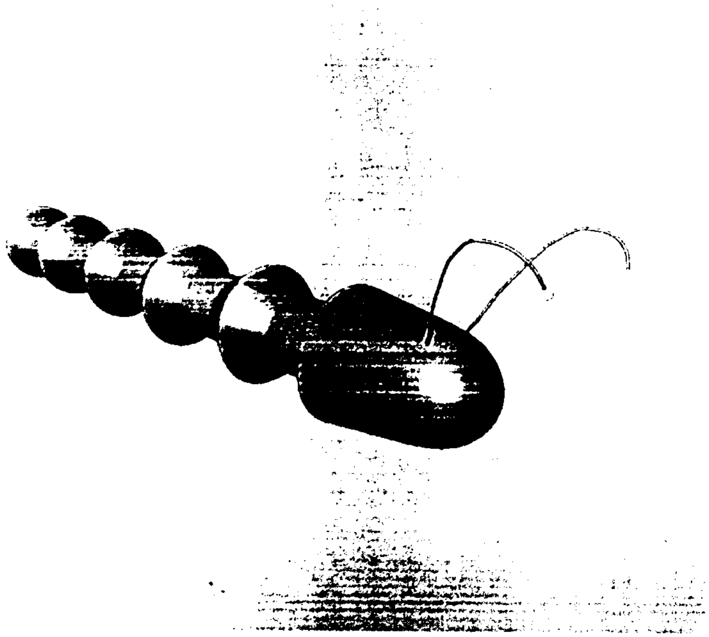
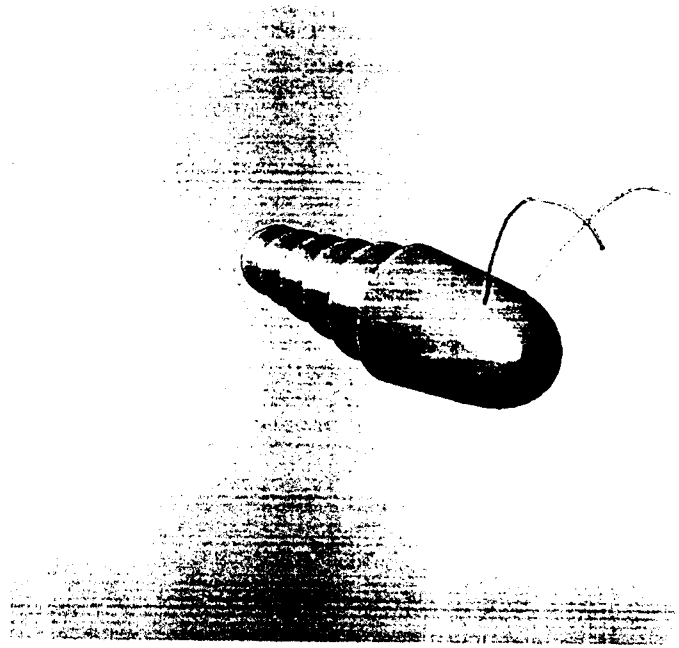
WORM ROBOT FOR IN-SITU EXPLORATION



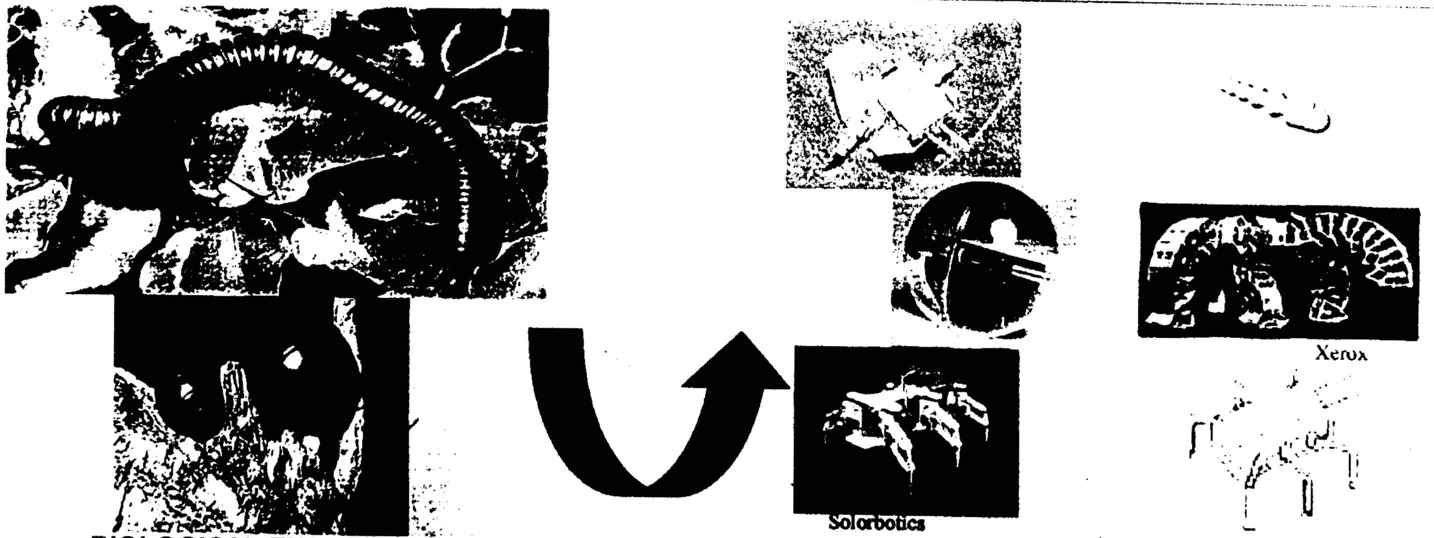
EXTENDED CONFIGURATION



CONTRACTED CONFIGURATION

*Z. Gorjian and S. Thakoor, "Biomorphic Explorers Animation Video", 1st NASA/JPL WORKSHOP ON BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS, August 19-20, 1998; Jet Propulsion Laboratory, Pasadena, CA

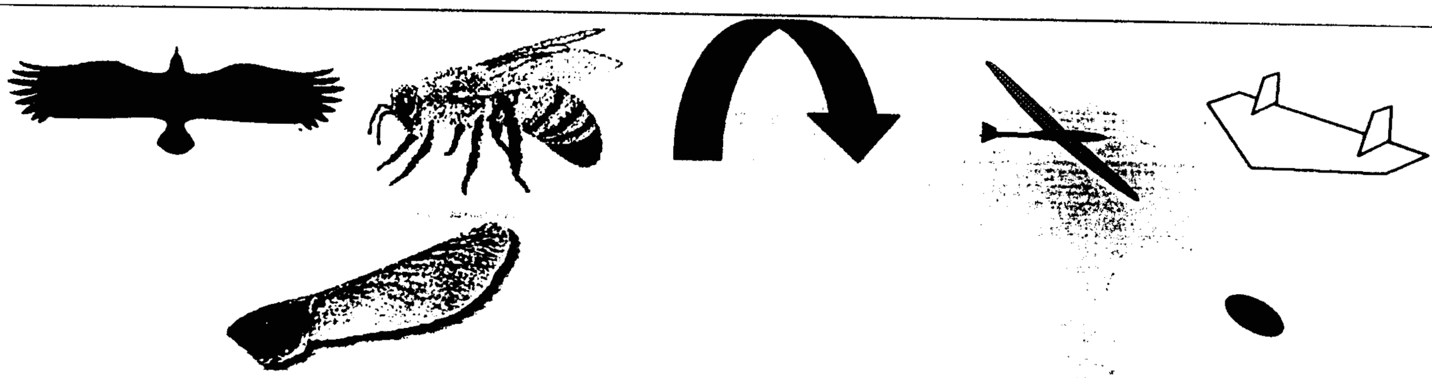
BIOMORPHIC EXPLORERS: VERSATILE MOBILITY



BIOLOGICAL EXAMPLE OF RECONFIGURABLE MOBILE UNIT

CHALLENGE: TO DESIGN RECONFIGURABLE MOBILE UNIT

SURFACE/ SUBSURFACE



BIOLOGICAL EXAMPLES OF FLYERS

BIOMORPHIC FLIGHT SYSTEMS DOD LEVERAGE

FLYERS

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Biomorphic Flight Systems

- Extended reach over all kinds of terrain
- Unique perspective for IMAGING, SPECTRAL SIGNATURE, ATMOSPHERIC MEASUREMENTS
- Deploy/Distribute Payloads
- Many biomorphic explorers(seedwing flyers, crawlers, burrowers, gliders etc) work in cooperation with larger UXV'S to enable new missions and achieve successfully currently UNATTAINABLE MISSIONS

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Comparison of Biomorphic Flight System Concepts for Mars

Parameter		Class: Powered µFlyer	Glider	Seed Wing Flyer
Lift Generation		Wing	Wing	Rotating Wing
Method of Propulsion		Propeller	Gravity	Gravity
Energy Storage		Li Battery	Altitude	Altitude
Total Mass	(g)	57	57	57
Payload Mass (%)	(g)	**6 (~10 %)**	**32 (~ 50 %)**	**52 (~ 90 %)**
Wing Span	(m)	0.194	0.194	0.19
Volume	(cm³)	**380**	**230**	**77**
Flight Speed	(m/s)	84	84	19
Range	(km)	10	50	0
Duration	(s)	**120**	**700**	**790**
Starting Altitude	(km)	0	10	10

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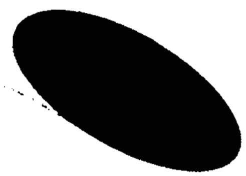
Seed Wing Flyers

- **Simpler and smaller than parachute on small scale for dispersion of sensors and small surveillance instruments.**
- **Controlled Descent Rate ~ 15 m/s (on surface of Mars)**



(b)

(a)

Maple Seed Samara

Design Goals:

•Small total mass, ~100 g
•High payload mass fraction, > 80%
•Captures key features of controlled and stable descent as observed in Samaras, such as maple seeds
•Reliable, minimal infrastructure
•unobstructed view overhead for atmospheric measurements
•simple construction, few constituent parts

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Biomorphic Controls in Seed Wing Flyers:

Active control of seed wing descent is a significant concept for further development to impact the usefulness of seed wing flyers. This is an effort to influence the direction of descent, by periodic movement of a control surface on the wing portion. For example, a simple wing structural element made of advanced piezo-polymeric composite actuators could play a dual role as a structural member as well as an active control element when activated, altering the lift characteristics for a fraction of one rotation. The signal to drive the structural element would be generated by the measurement of sunlight on the upper payload surface. That signal would normally vary with rotation due to changing sun angle. Detection of a certain part of that periodic signal would be programmed to activate the change in wing shape. Thus, the seed wing would tend to move in a consistent pattern relative to the sun direction. Individual seed wings in an ensemble could be programmed to have varying solar response patterns, ensuring that the group travels away from each other, for maximum dispersion in the landing location.

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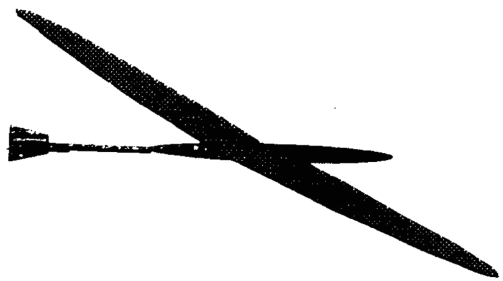
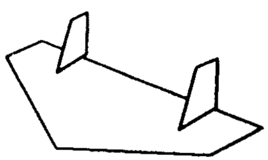
Biomorphic Gliders

- Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.





- small mass (100 g - 1000 g)
- low radar cross section
- larger numbers for given payload due to low mass
- amenable to cooperative behaviors
- missions use potential energy: deploy from existing craft at high altitude
- Captures features of soaring birds, utilizing rising currents in the environment
- *Adaptive Behavior*
- *Self Repair features*

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Biomorphic Missions, formulated within the last few years are hybrid aerial-surface missions that maximize the mission outcome by synergistic use of existing/ conventional surface and aerial assets along with biomorphic explorers. Just as in nature, biological systems offer a proof of concept of symbiotic co-existence, the intent here is to capture/imbibe some of the key principles/success strategies utilized by nature and capture them in our biomorphic mission implementations

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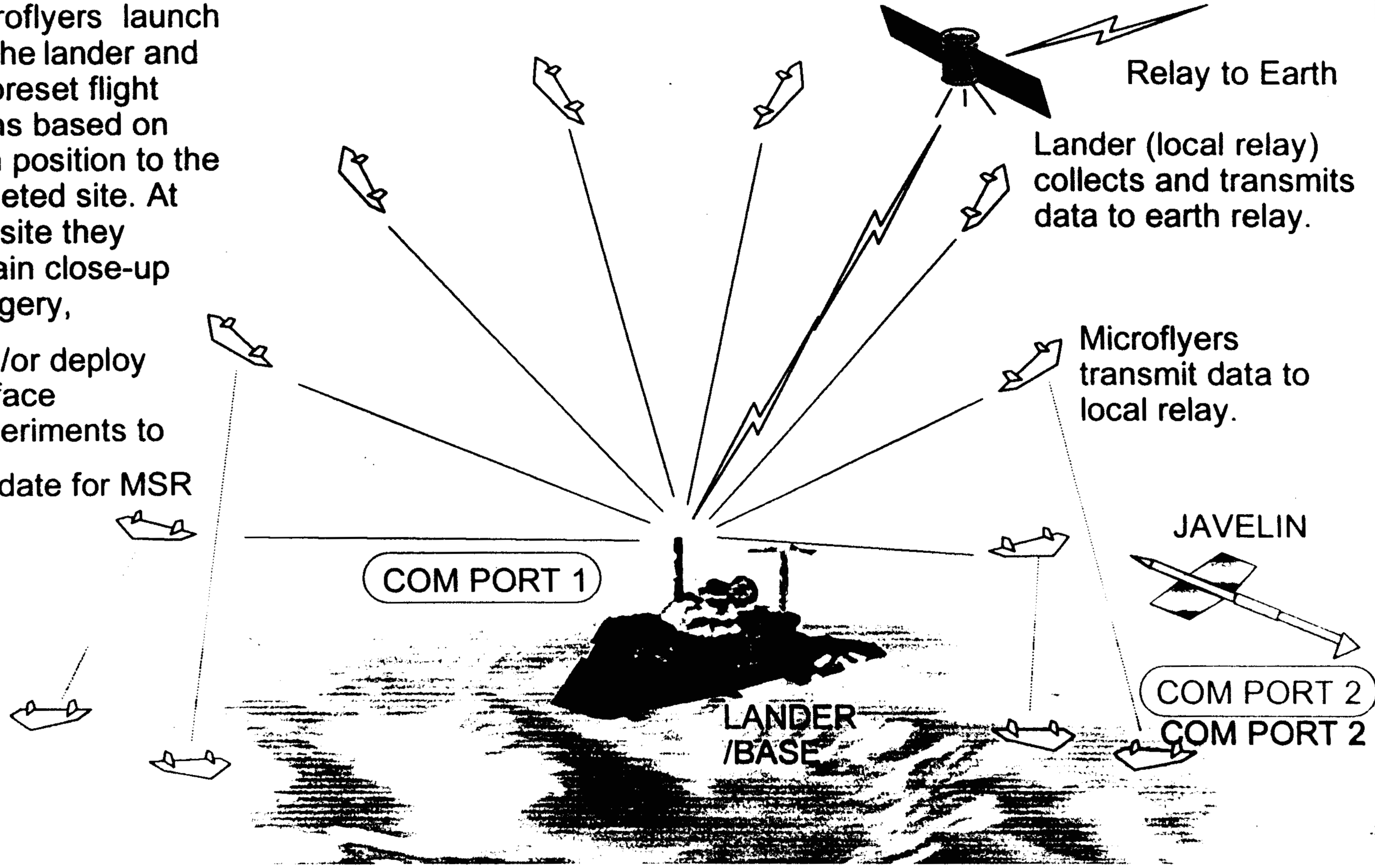
Surface Launched Micro-Gliders

Microflyers launch off the lander and fly preset flight plans based on Sun position to the targeted site. At the site they obtain close-up imagery,

and/or deploy surface experiments to

validate for MSR



Surface launched microflyers work in synergy with the surface systems to enable new science/applications . Lander provides a robust communication route for imagery dowlink from the micro-glider

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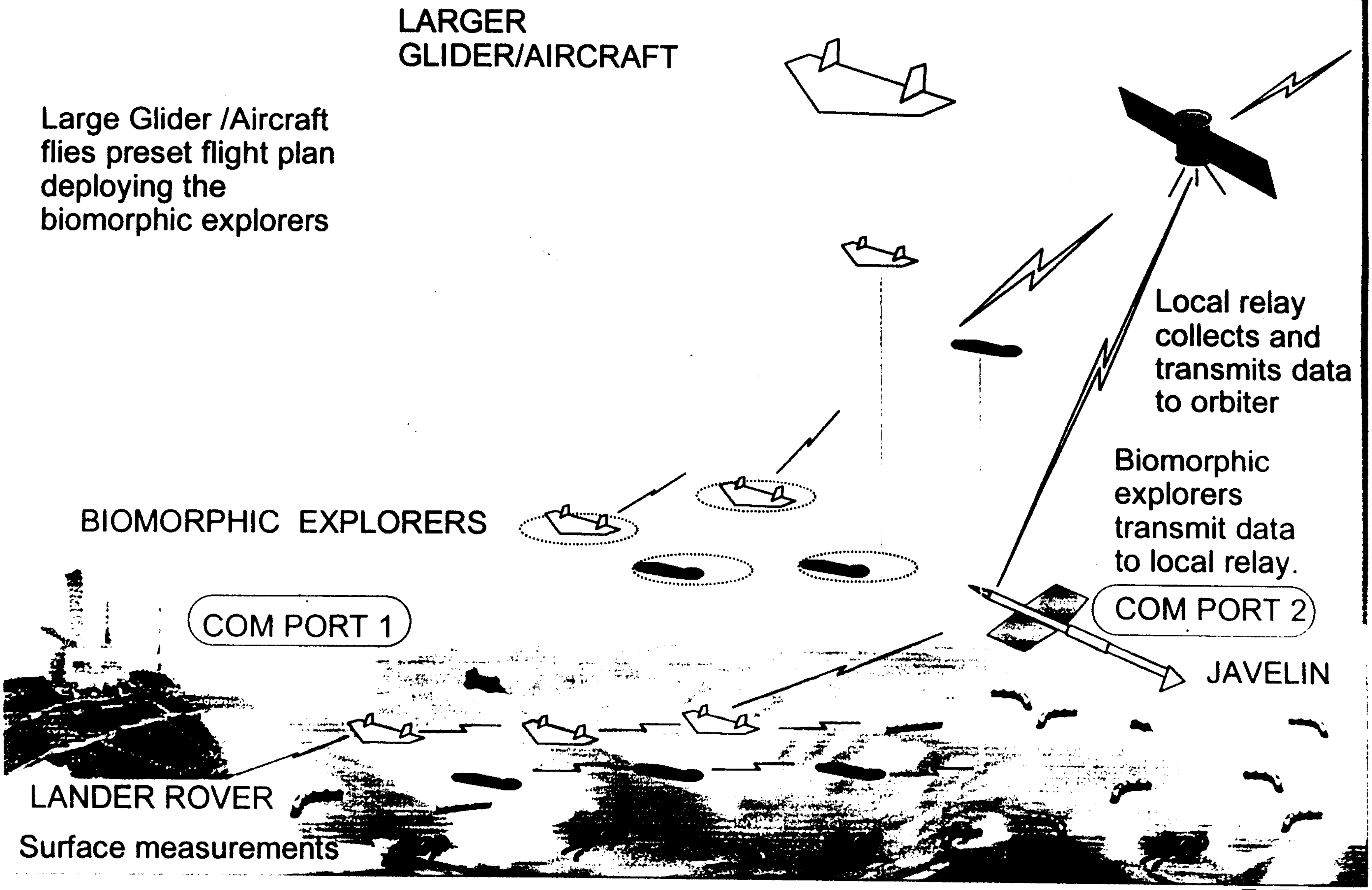
Biomorphic Explorer Deployment Concept:
missions use potential energy:deployed from existing craft at high altitude



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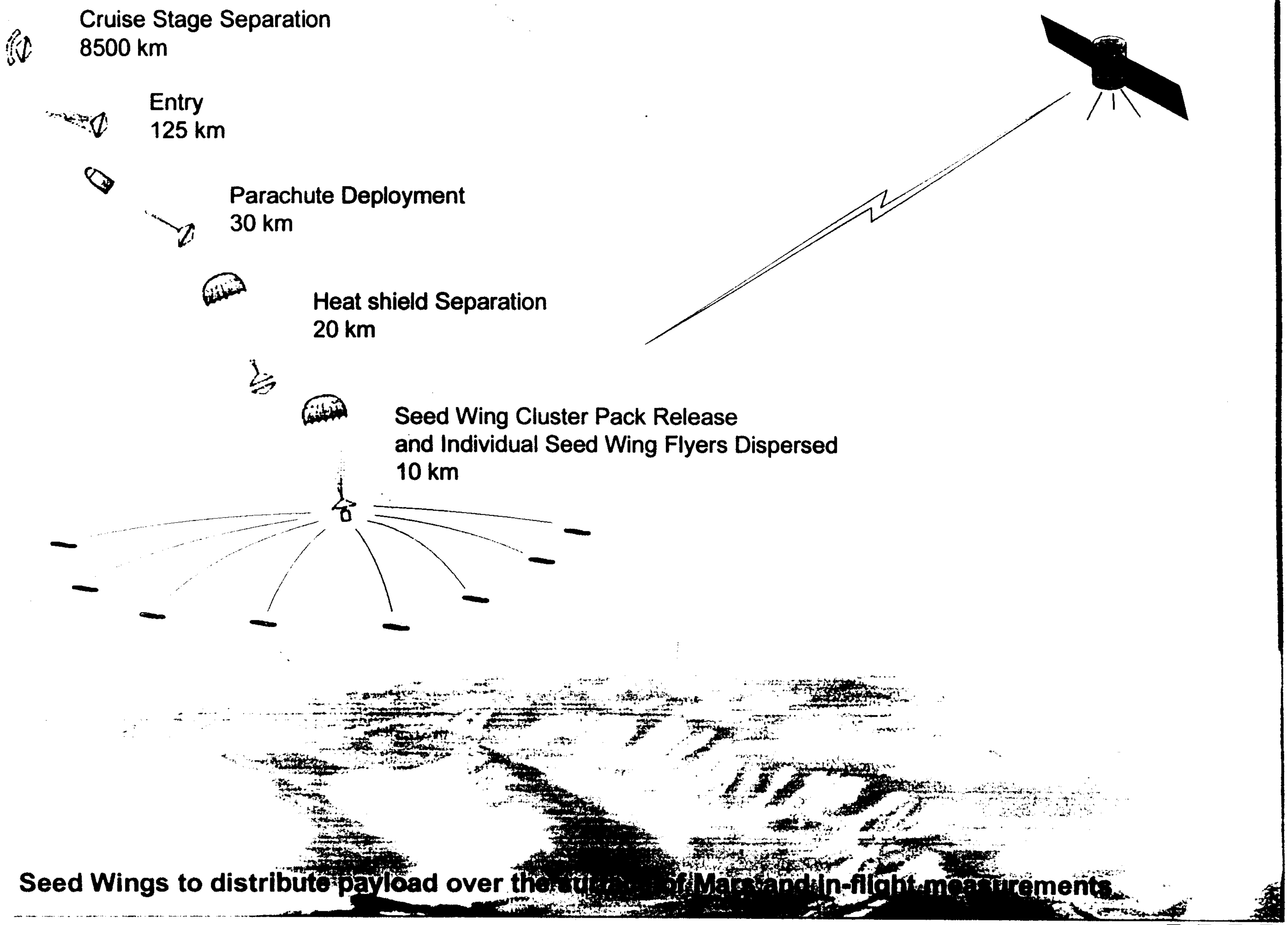

Seed Wings to distribute payload over the surface of Mars and in-flight measurements

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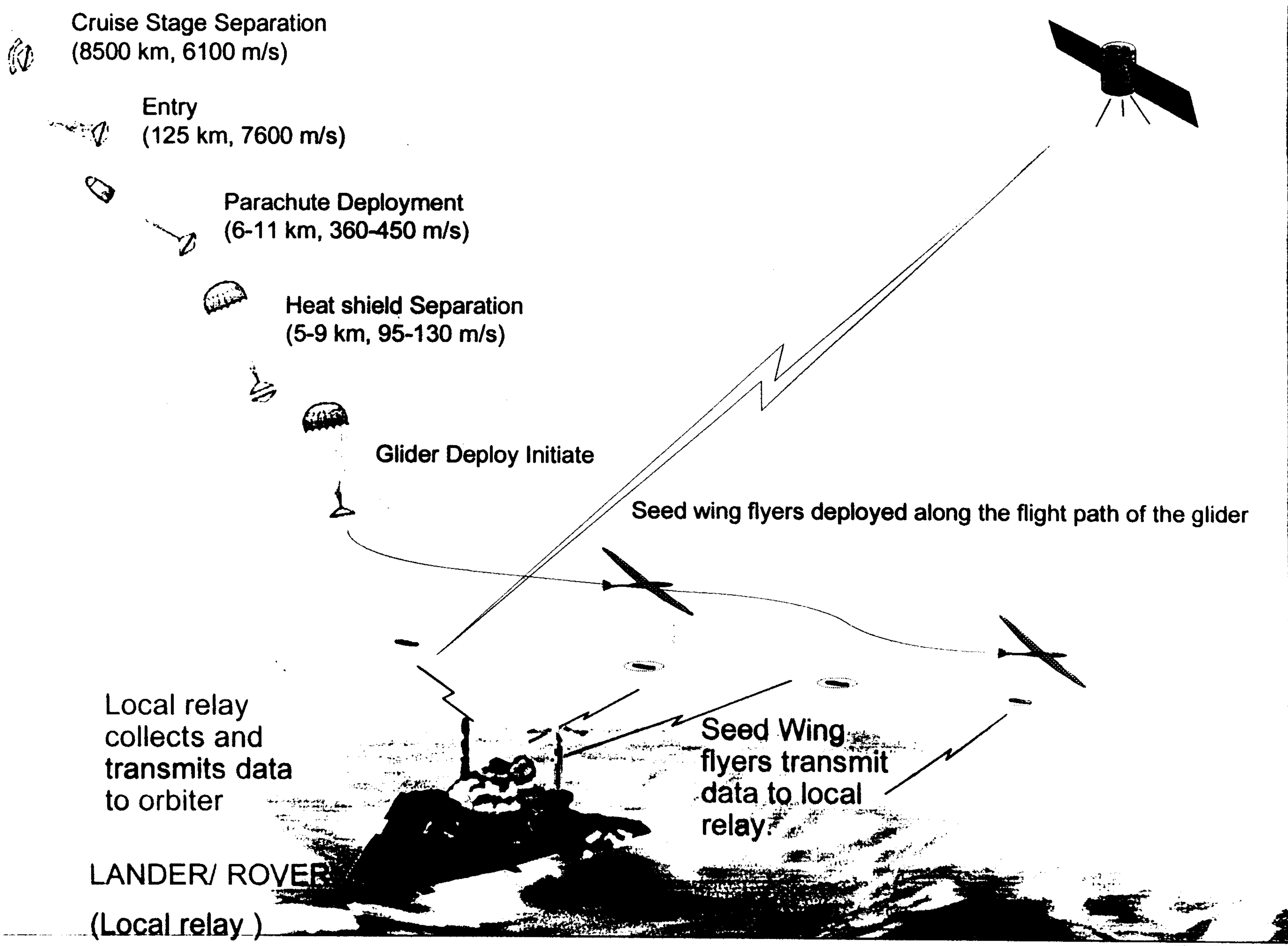

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- An auxiliary payload of a Mars Lander (2-10kg)
- Micro-gliders (4 - 20) launched/deployed from the Lander
- Lander serves as a local relay for imagery/data downlink
- Micro-Glider provides :
  - Close-up imagery of sites of interest (~ 5-10 cm resolution)
  - Deploys Surface payload/experiments (20g - 500 g)
  - In-flight Atmospheric Measurements
  - Candidate instruments
    - Camera (hazard & slope identification by close-up imagery)
    - Meteorological suite (in-flight atmospheric measurements)
    - Microphone to hear surface sounds, wind and particle impact noises
    - Electrical Measurement of surface conductivity
    - Accelerometer Measurement of surface hardness
    - Seismic measurement (accelerometers)

- 50m-500m height, unique and essential perspective for imaging
  - 1-10 Km range, wide area coverage very quickly
  - useful close-up imagery and surface payload deployment
- 2003/2005 Missions - Scout Missions, Sample Return Missions 2007 and beyond

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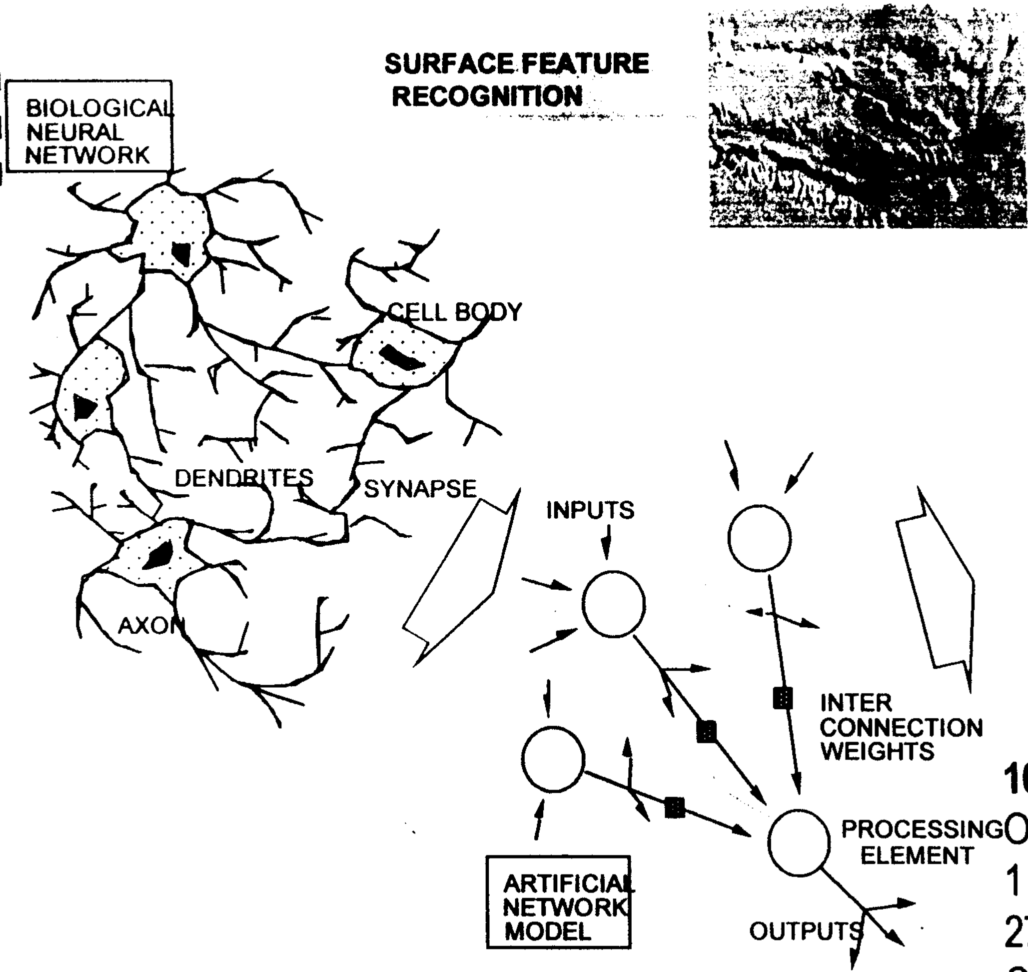
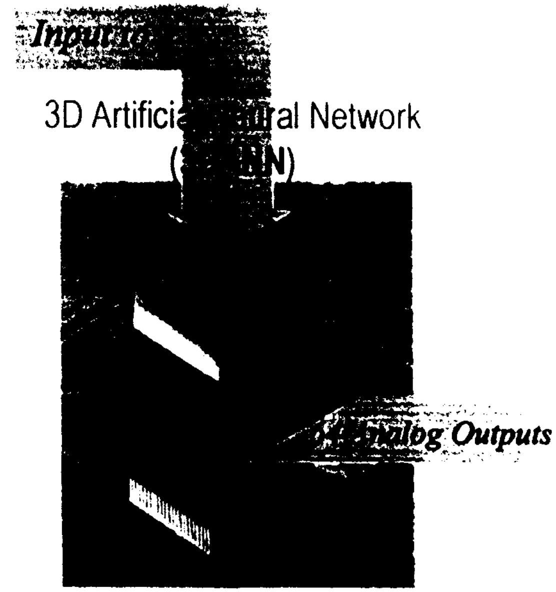
Enabling Processor for Surface Feature Recognition

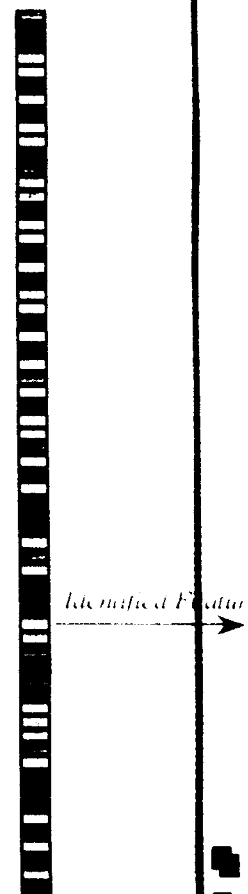
SURFACE FEATURE RECOGNITION



TOPOGRAPHY MAP



FEATURE LIBRARY



10 gm, 5 cc, 2 W
On-chip IR detector
1 trillion 8-bit multiplies/sec
270 million template matches/sec
Compute power greater than fast supercomputer

JPL neural network chip design enables the 3DANN technology that delivers unprecedented processing speed for ATR: ***(64 convolutions of 64x64 masks in 16 msec vs. 2 hours on state-of-the-art workstations)***

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Science Objectives:

- Near Term 2003/2005
  - Image surface topography
  - Characterize terrain around lander
  - Identify rocks of interest for rover
  - Distribution of Instruments/Experiments/Surface explorers to targeted sites

- 2005 - 2007
  - Identify and collect sample enabling sample return

- Long Term 2007 and beyond
  - Co-operative Operation of a multitude of Explorers together to obtain imagery, and deploy surface payloads

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SUMMARY & ROADMAP

Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost

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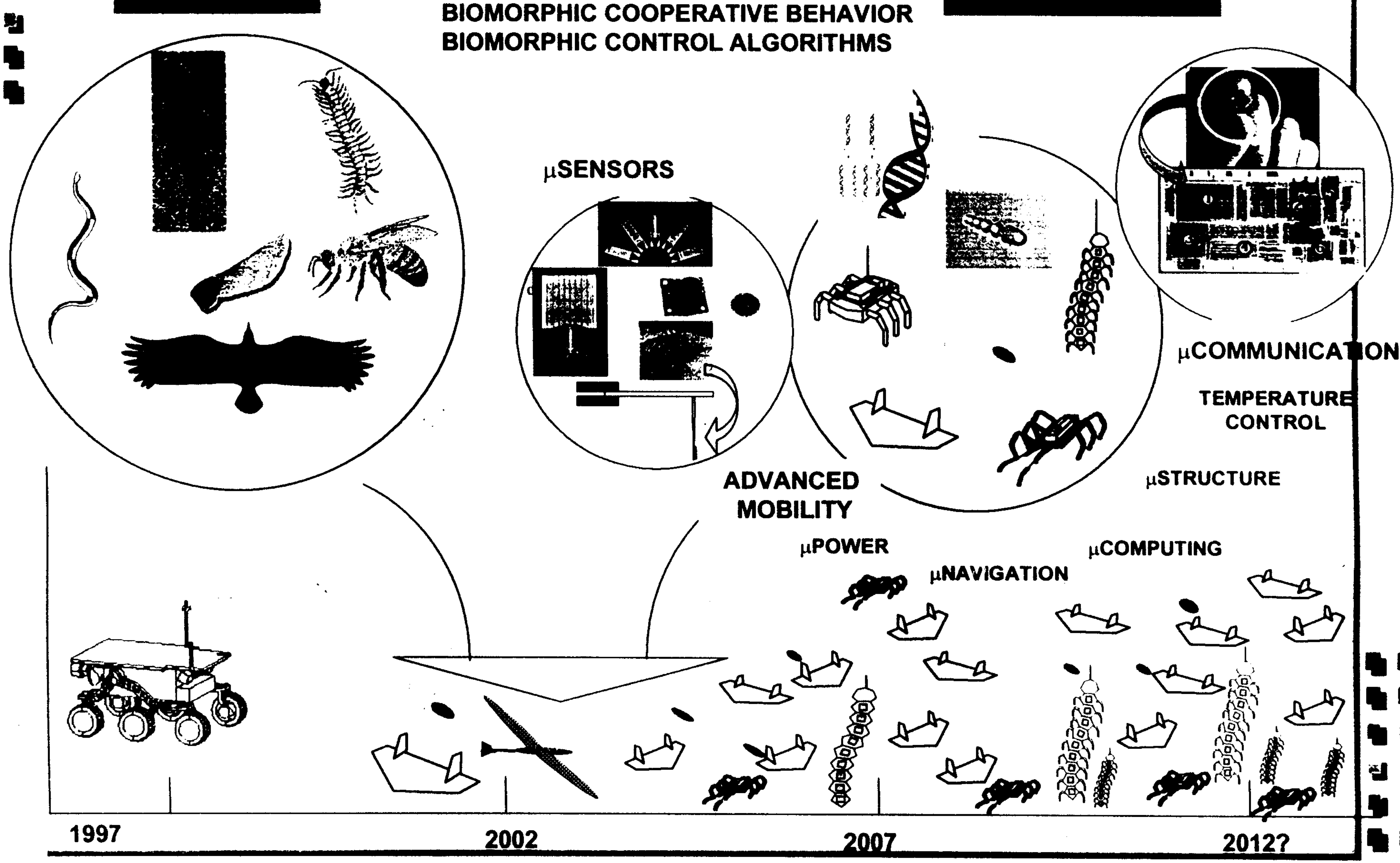

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Abstract Submission to the 4th IAA International Conference on Low Cost Planetary Missions to be held May 2 - 5, 2000 at The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland USA

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Sponsored by NASA